



## Offshore wind technology, possibilities and trends

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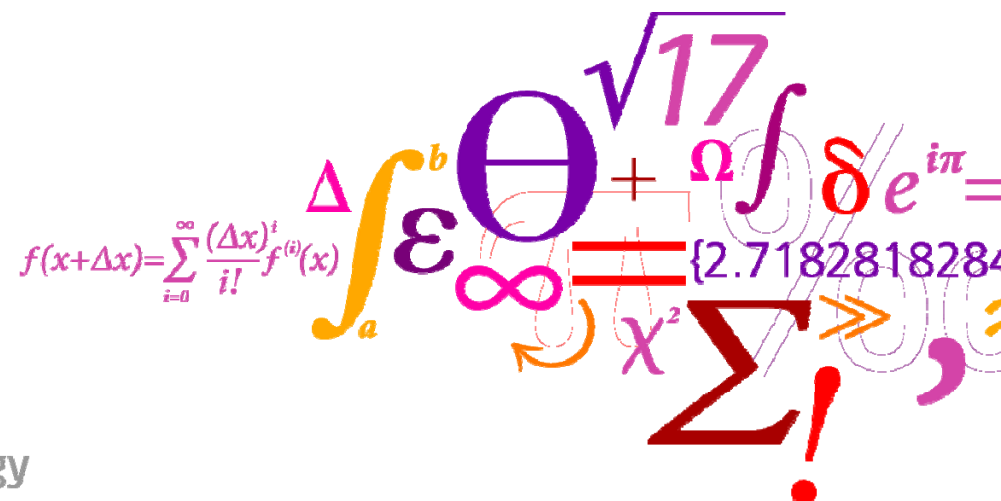
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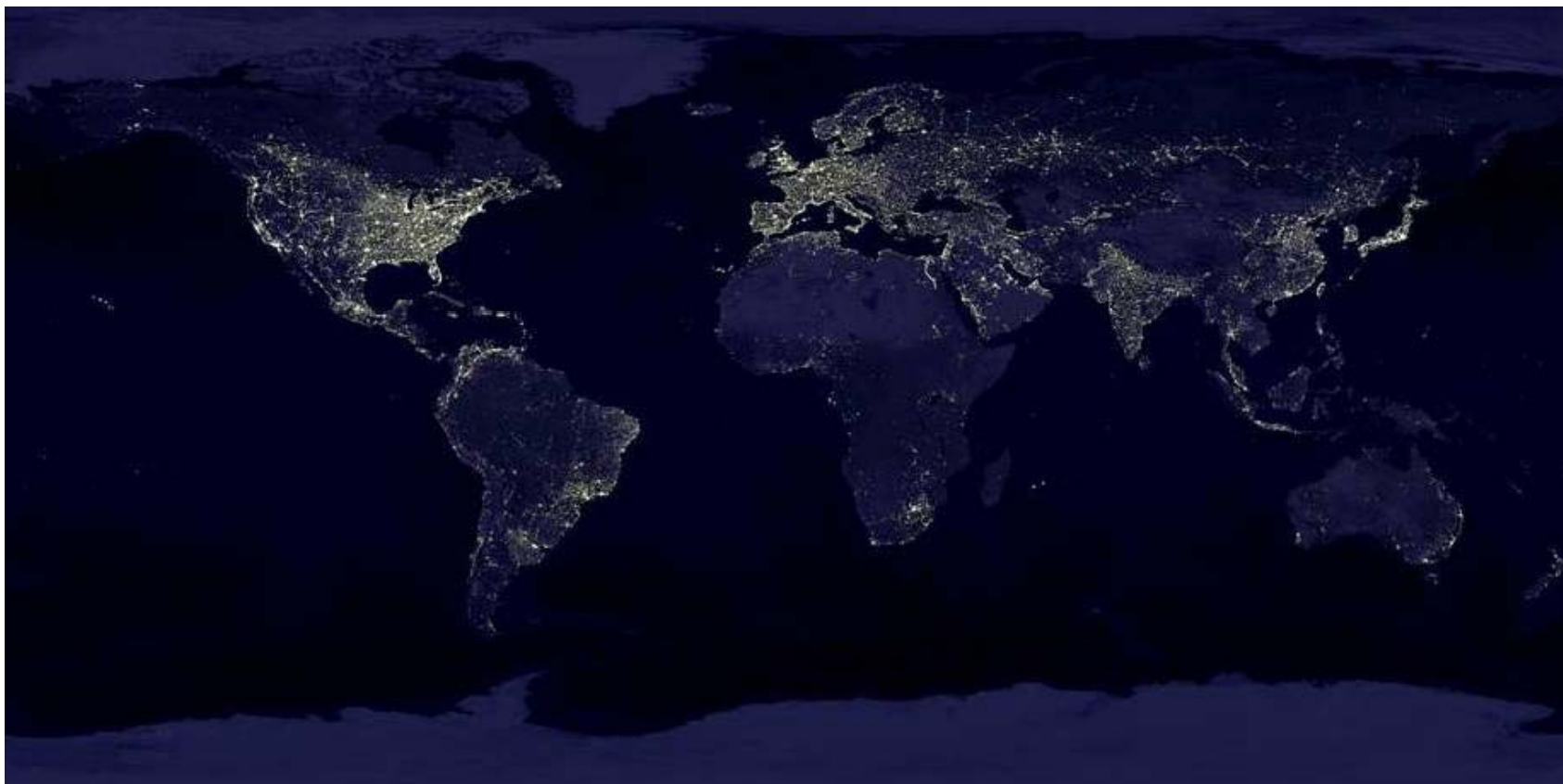
# Offshore wind technology, possibilities and trends

Peter Hauge Madsen  
Flemming Rasmussen  
Peter Hjuler Jensen

Presented at Risø International Energy Conference 2009

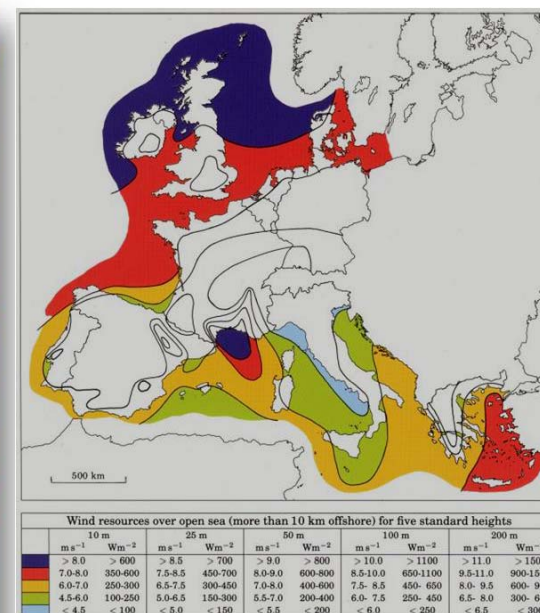
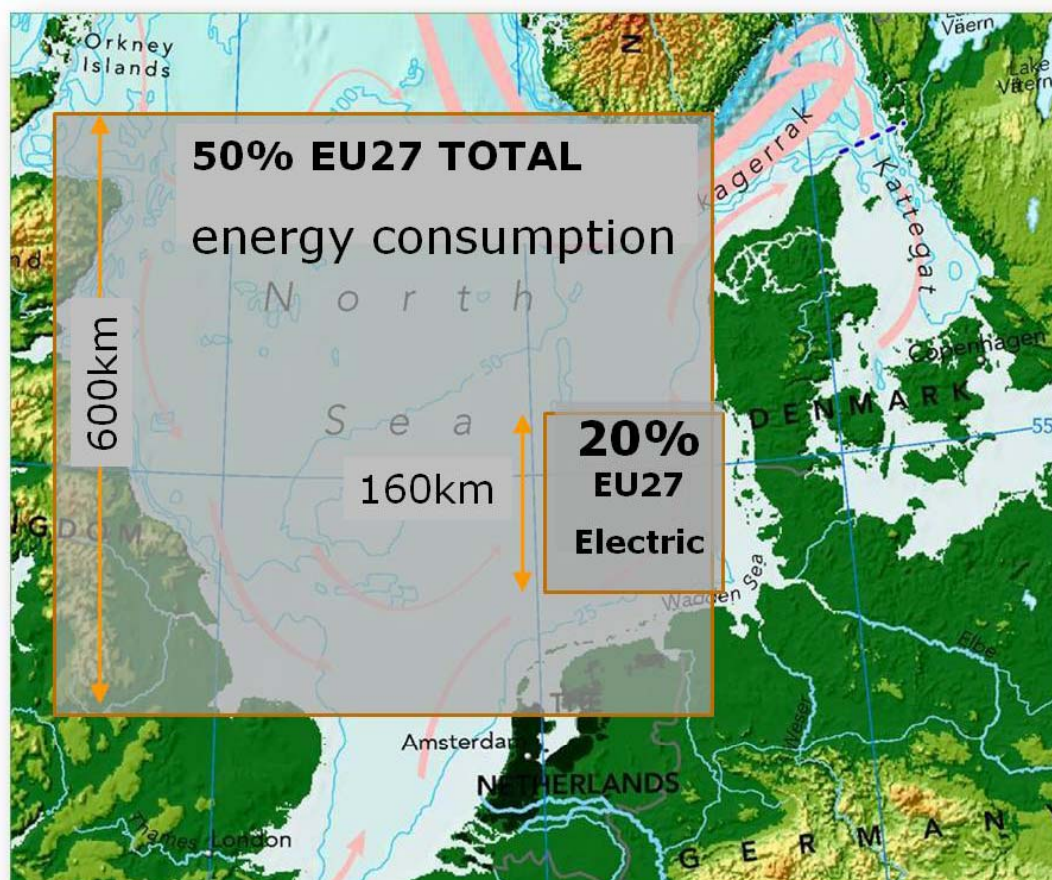


## Population centres often at the coast



# Abundant resource

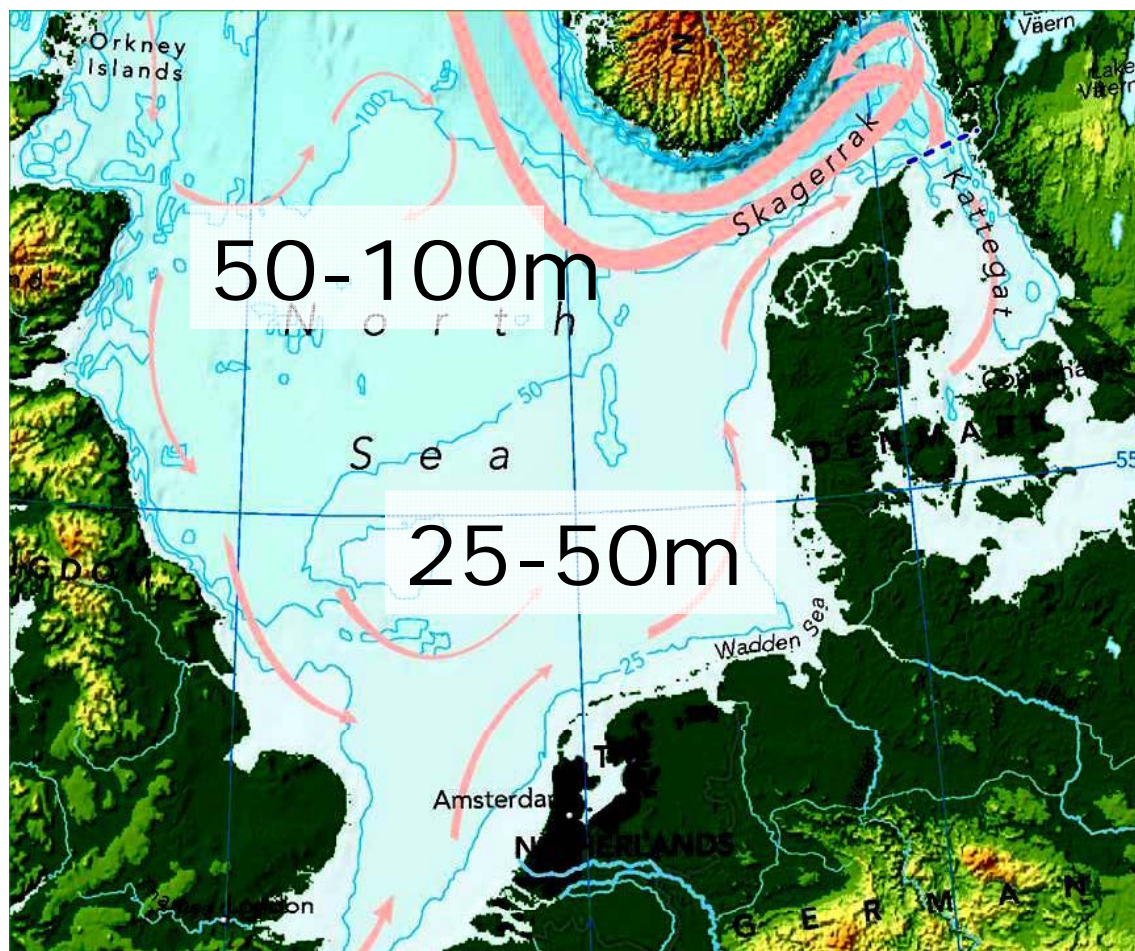
## EU27 power from the North Sea





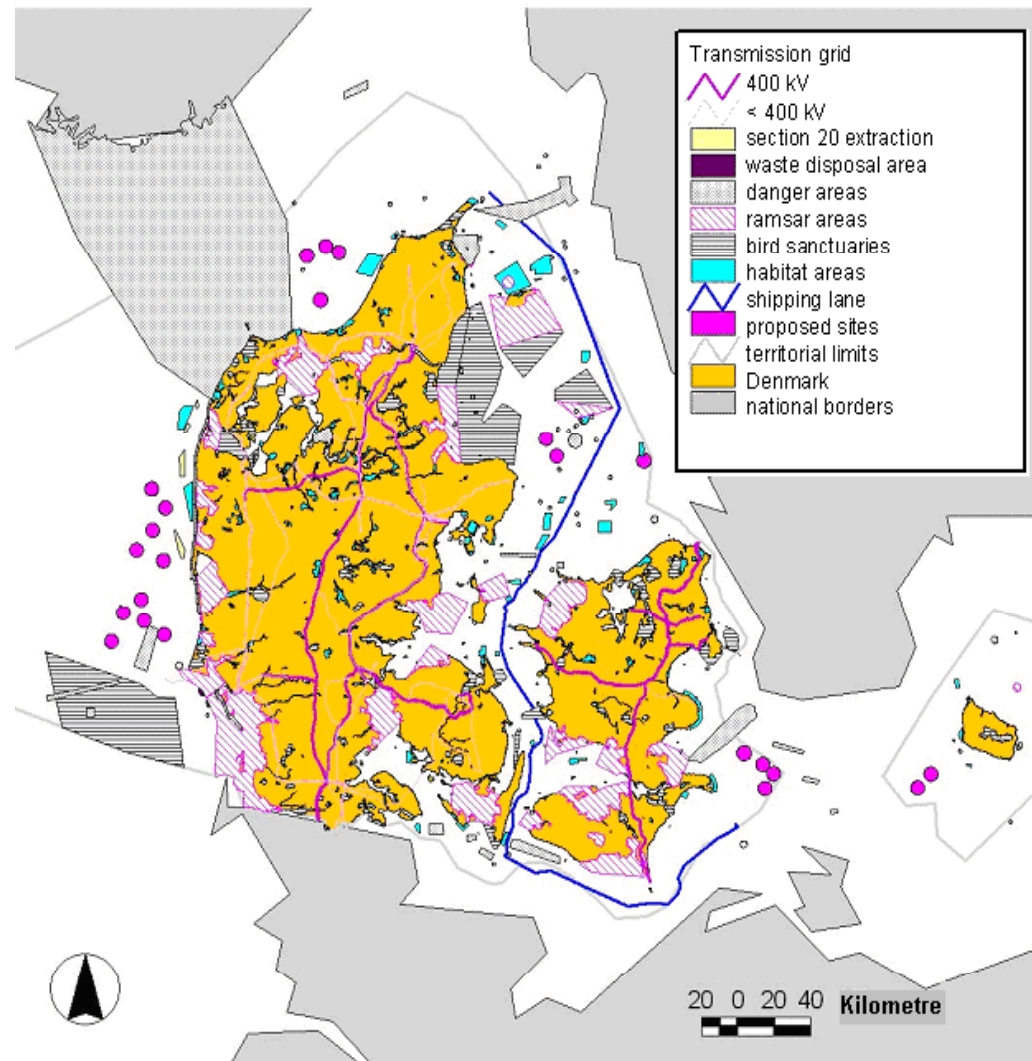
# The wind pits of Europe – The North Sea

- Excellent wind resources 10-11 m/s average
- Manageable water depths
- Large population densities around it
- Vast in size

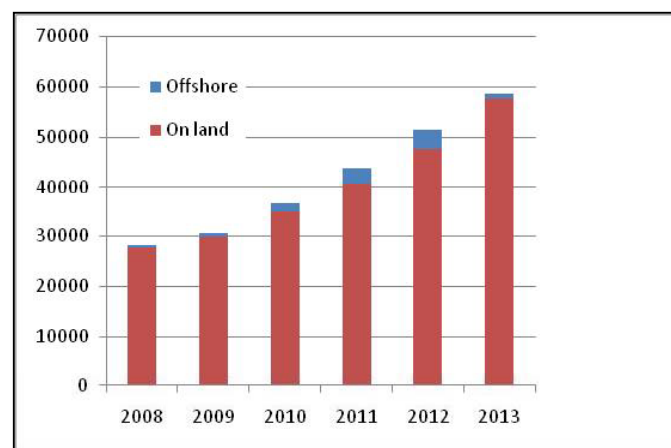
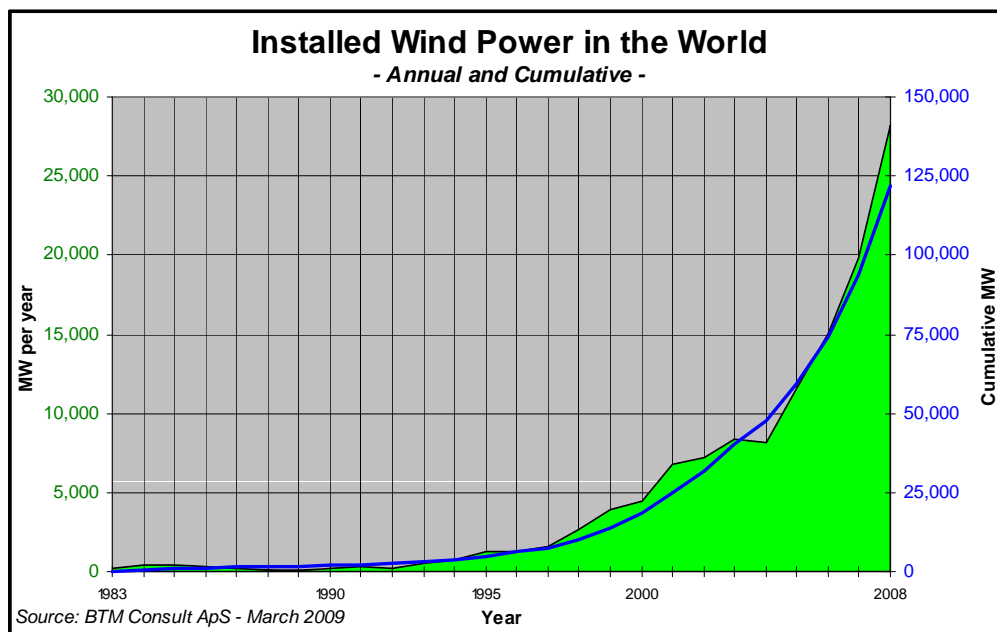


# Available areas - Plans for future offshore wind farms in Denmark

- Status 2008 – 3163 MW, 423 MW offshore
- 2009-2012 additional 840 MW offshore
- Report on future Offshore sites, Update of action plan from 1997
- 23 Sites each 44 km<sup>2</sup> for a capacity of 4600 MW Wind Power
- Production 18 TWh, or just over 8% of total energy consumption in Denmark or approximately 50% of Danish electricity consumption



# World market for wind energy – 2008



World Market Update 2008

## GLOBAL STATUS

- 28 GW installed in 2008
- 122 GW installed in total
- ~1% offshore 2008
- ~3.4 % offshore 2013
- ~22 % in EU 2020 (40/180 MW)
- 1.3 % of global electricity
- Power-consumption growing 3.3% per year
- Wind power growing 25% per year
- Installed power doubles every 3 years
- Factor 10 in ~10 years
- Goal 2020: 12 %, 1200 GW

# Key development issues

## Short term

- Cost
- Reliability, maintainability, availability
- Design conditions and process
- Validation
- Grid integration

## Medium to long-term

- Cost
- Design methods
- Upscaling
- Larger waterdepth
- Grid integration
- New concepts

### Danish MEGAVIND Strategy -June 2008

Offshore technology, aiming to:

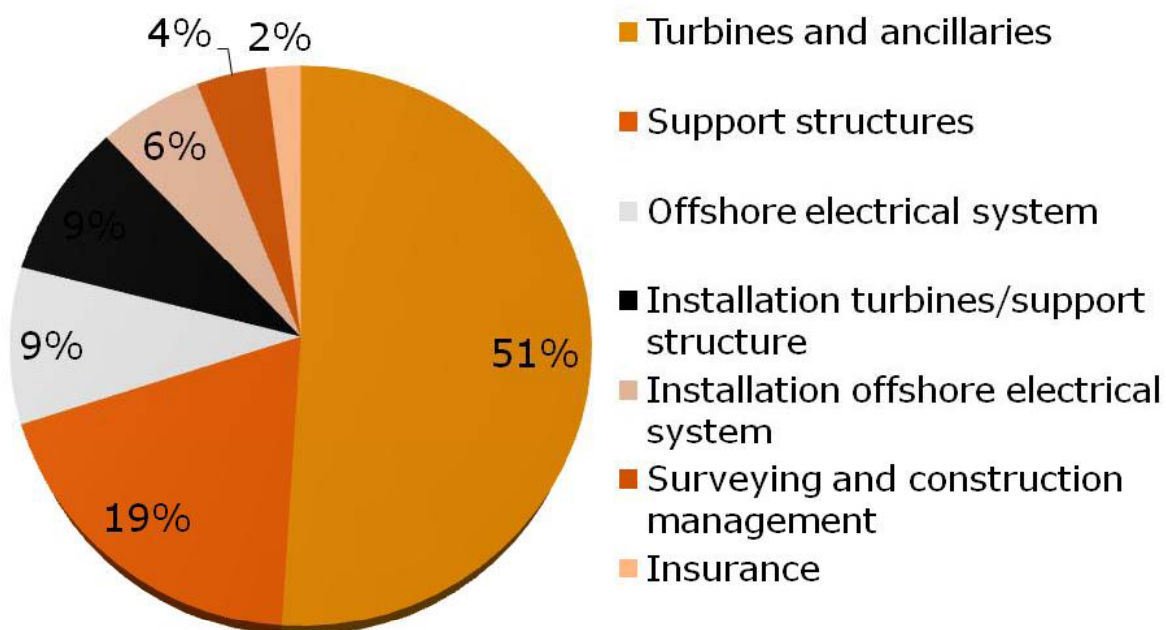
- develop new concepts for electrical infrastructure in offshore wind farms
- develop design procedures for the turbine, support structure and foundations to reduce design uncertainty
- develop and optimize concepts for foundations and installation, focusing on depths > 15m
- develop condition monitoring and data acquisition systems to map fault occurrences and optimize O&M
- improve access and safety
- improve knowledge of geotechnics and geophysics
- develop knowledge on materials with focus on corrosion
- develop optimal O&M strategies



# Costs - Offshore wind farms



## Capital Cost breakdown



Wind Energy – The Facts, EWEA, 2009

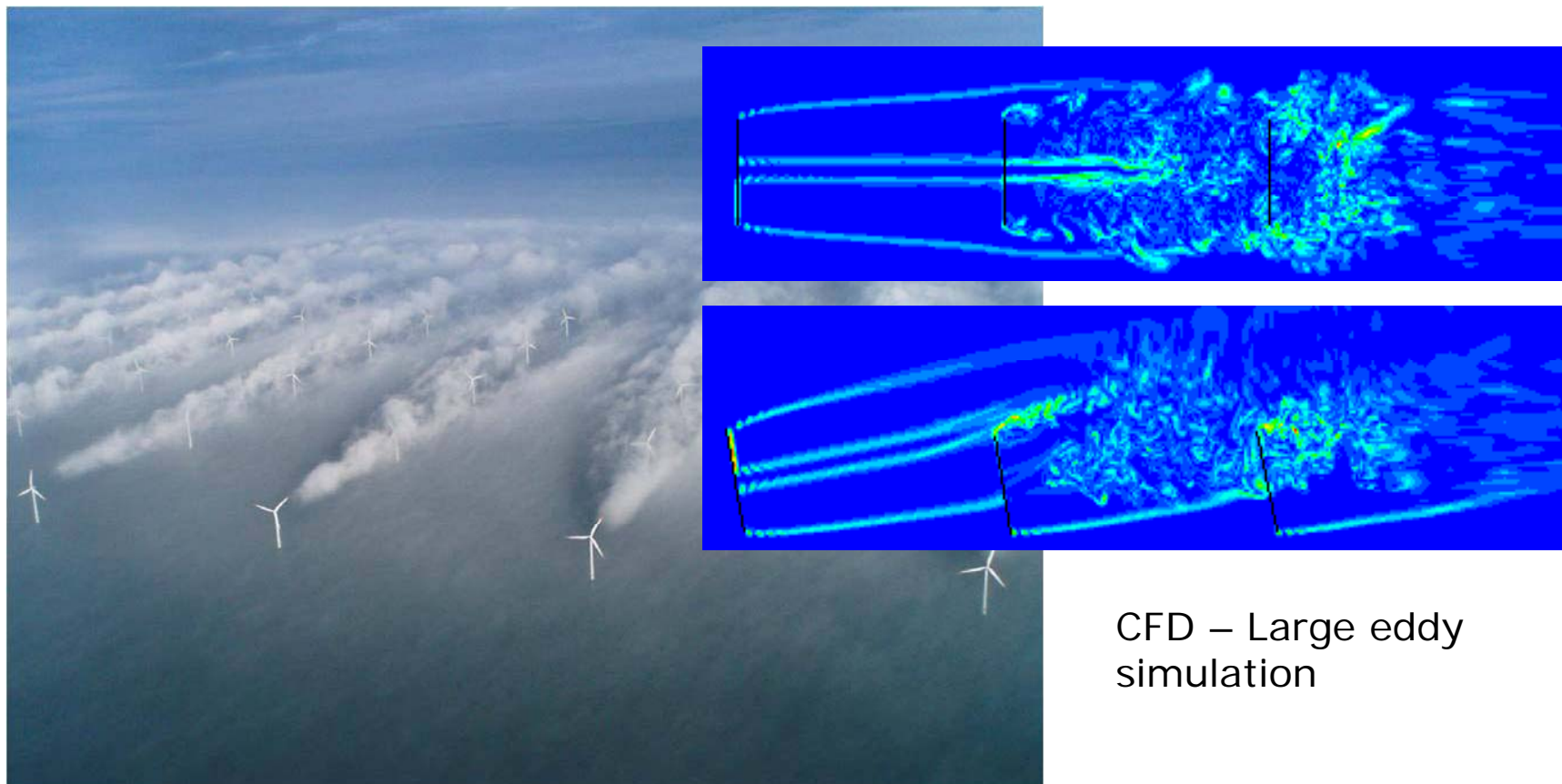
# Why Offshore Wind Differs from Traditional Offshore



- Offshore Wind Turbines Characteristics
  - Highly dynamic response
  - Strict eigen frequency requirements
  - Actively controlled load response
  - Wind and wake effects
  - Undamped cross-wind vibrations
- Design Considerations
  - 50-year return period on extreme event
  - Wind load dominated (water depth?)
  - Overall fatigue driven (incl. low cycle)
- Traditional Offshore Structures:
  - Passive in their load response
  - 100-year wave load dominated
  - Build-in structural redundancy

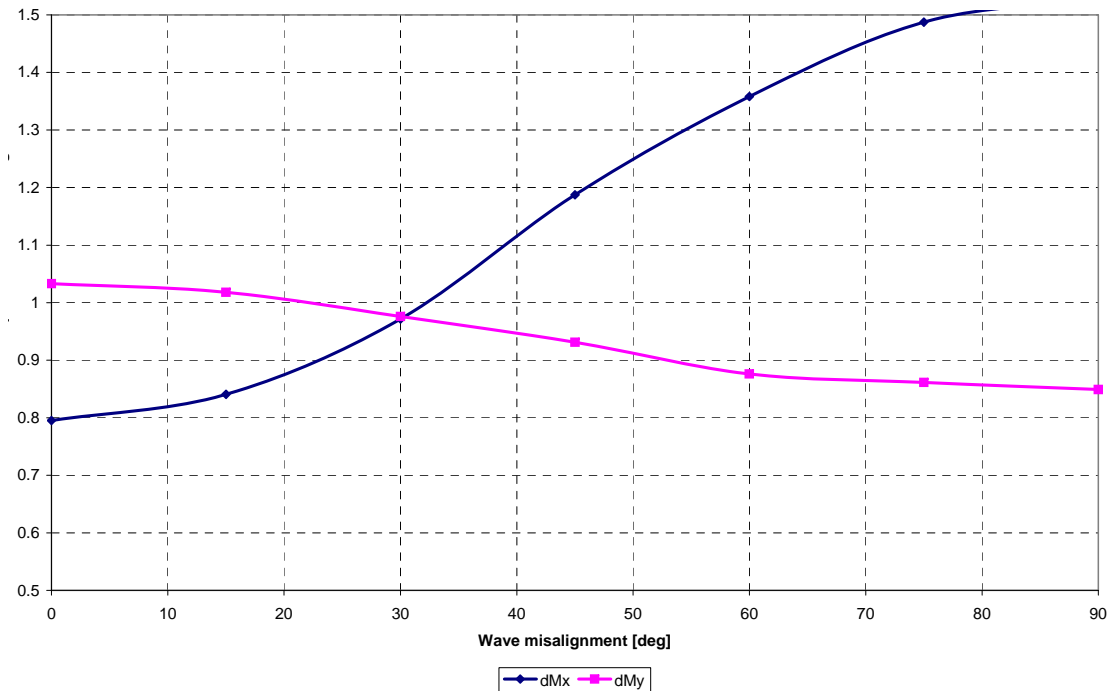
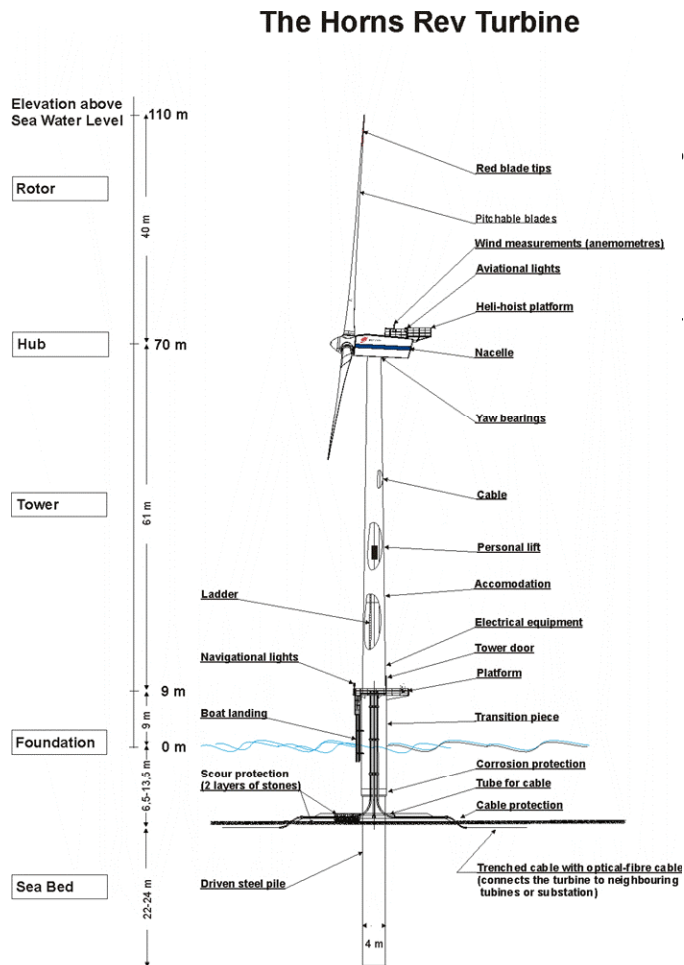
*Beatrice Offshore Wind Turbine - UK*

# Wind loads dominated by wake effects



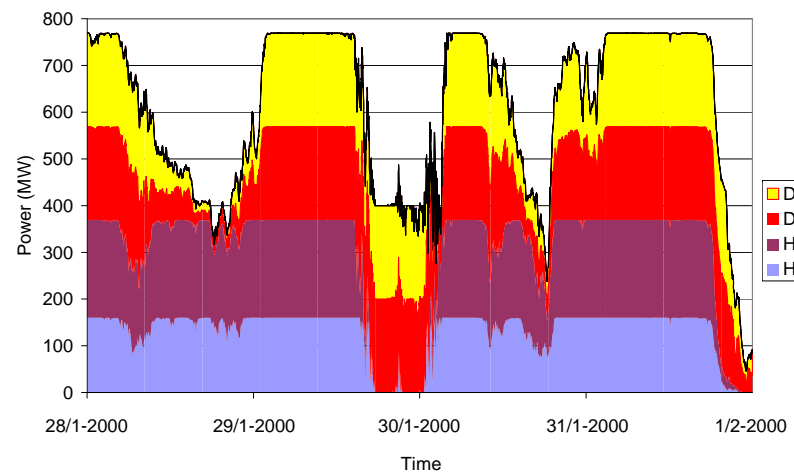
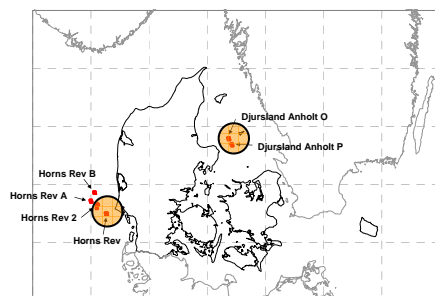
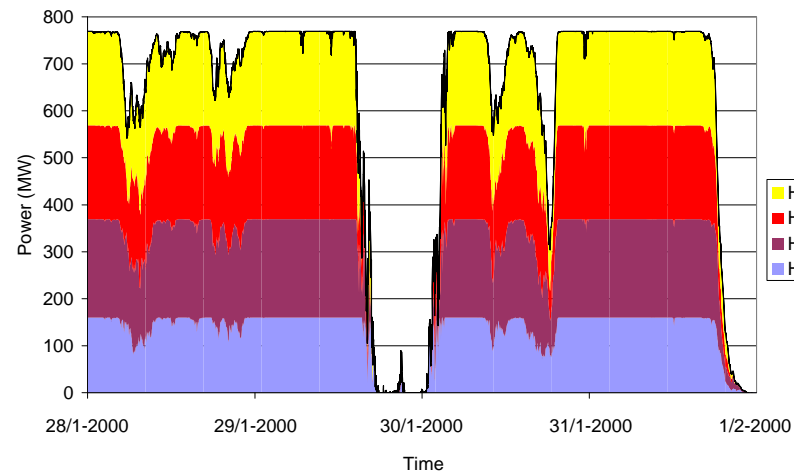
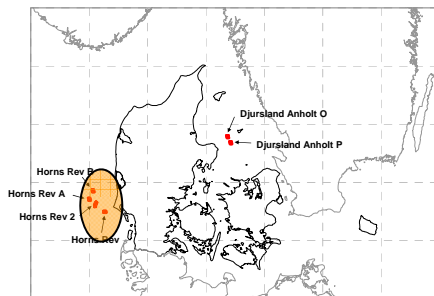
CFD – Large eddy simulation

# Influence of wind and wave directionality on fatigue loads at the mudline



***Normalised equivalent bending moment ranges at the mudline ( $f=0.33$  Hz)***

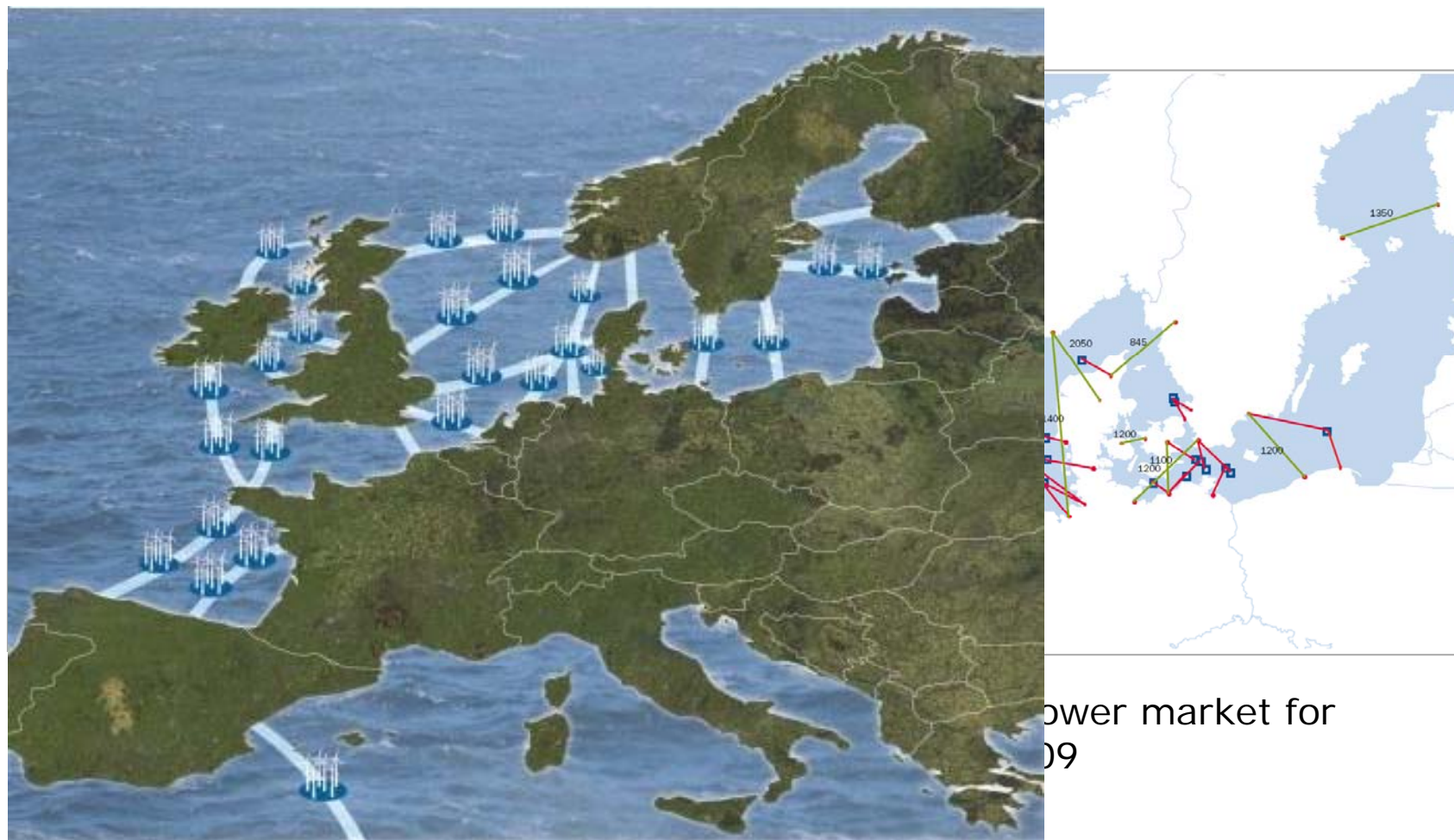
# Grid integration - Power fluctuations –2 cases



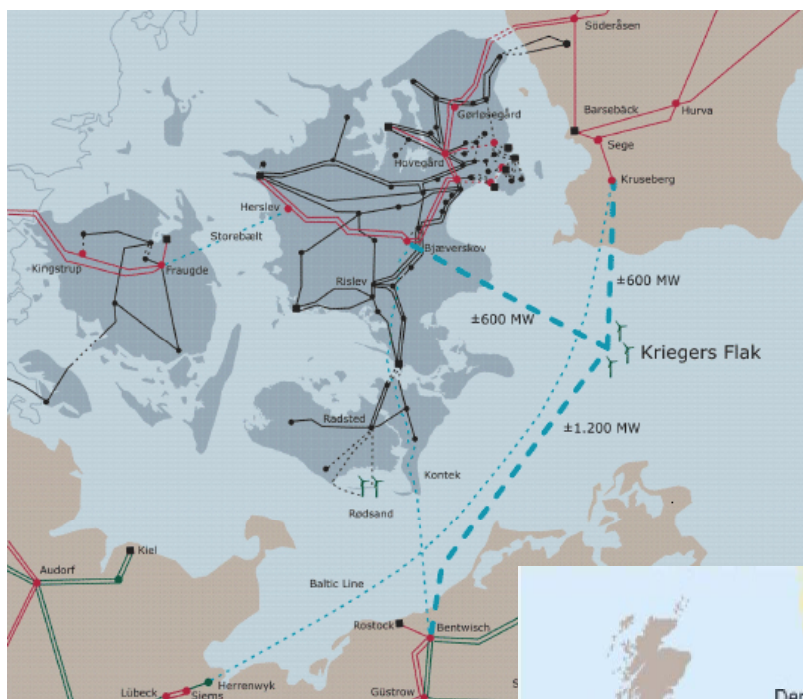


# Connection of offshore wind farms

## Radial or meshed



# Kriegers Flak – new concept for offshore wind farm connection



Both transmission of power to land grid and exchange of power

## Advantages:

Optimal regional economy

Improvement of market

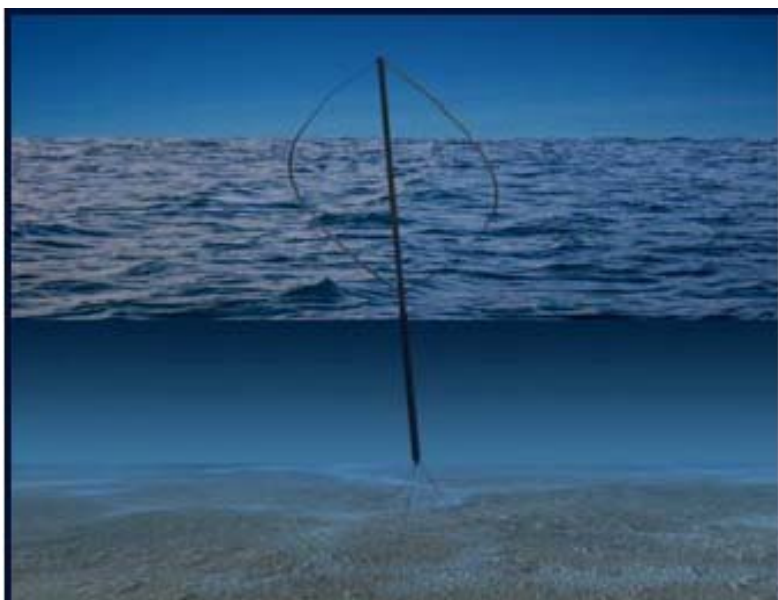
Added security of supply

Demonstration of new technology

Pilot project for the North sea

## Developments and innovation

- Upscaling
- Soft foundations
- Floating
- Combined wave and wind
- Vertical axis



Gravity causes **steady** loads

Aerodynamic loads are **~cyclic**

# UPWIND – EU Integrated project

## Objective:

Develop improved design models and verification methods for wind turbine components

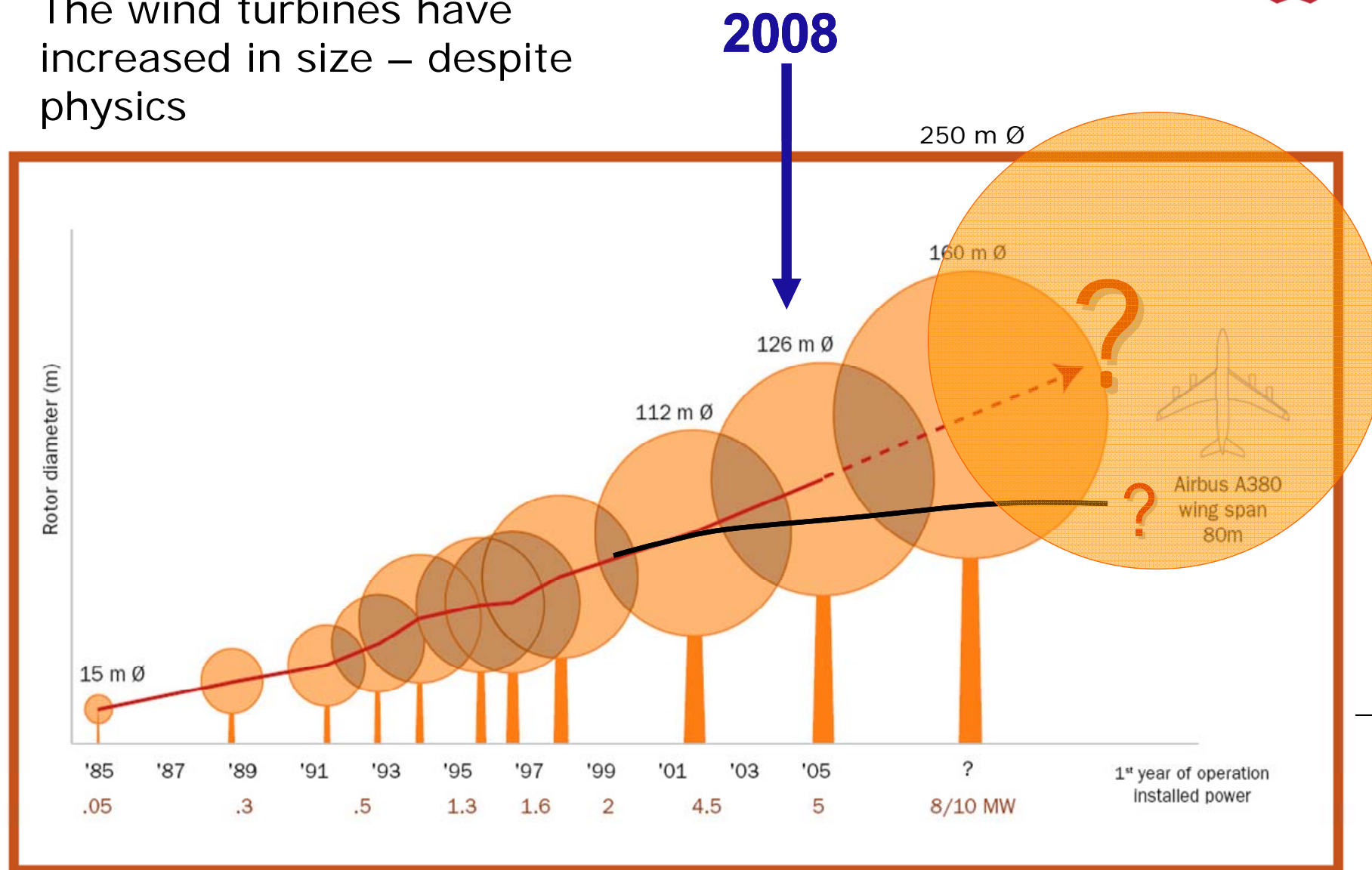
- Very Large Wind Turbines
- More Cost Efficient Wind Turbines
- Offshore wind farms of several hundred MW





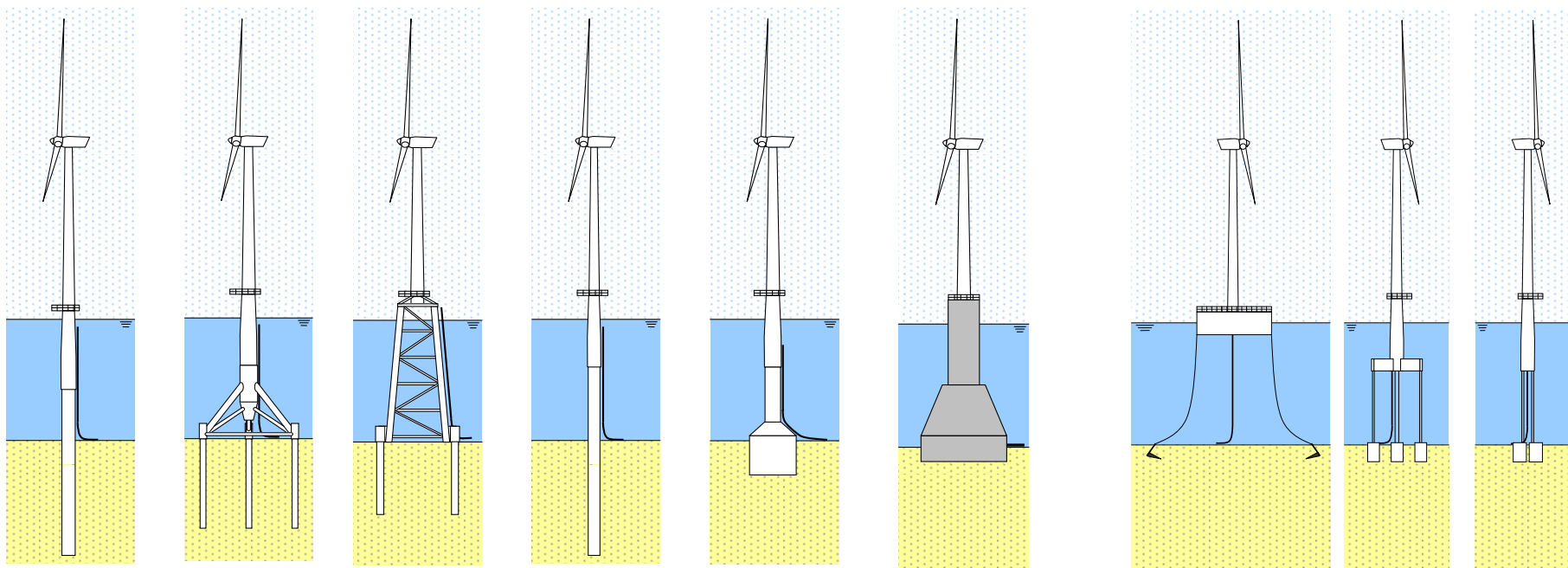
# Up-Scaling

The wind turbines have increased in size – despite physics

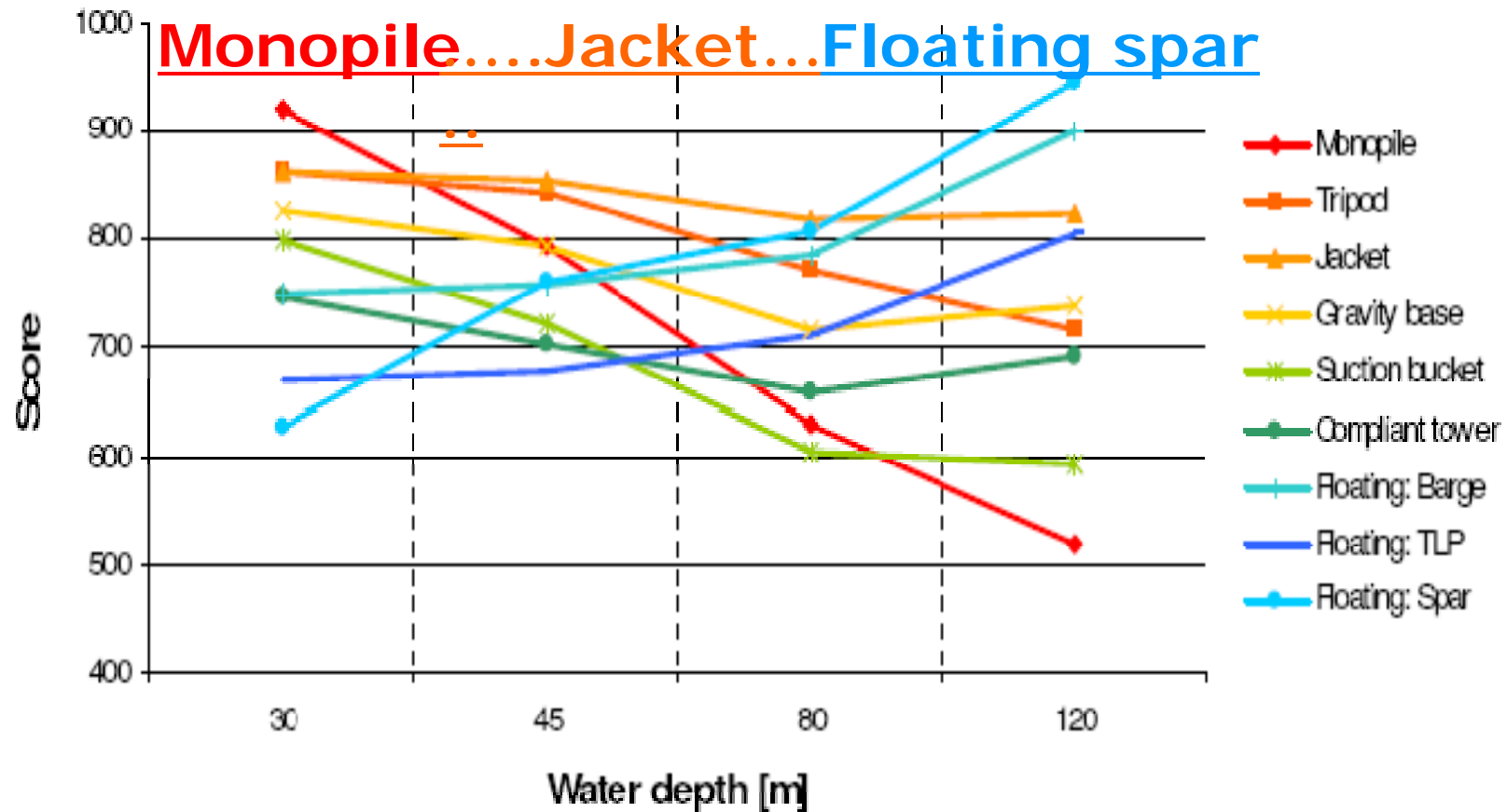




# WG 4 Foundations and support structures



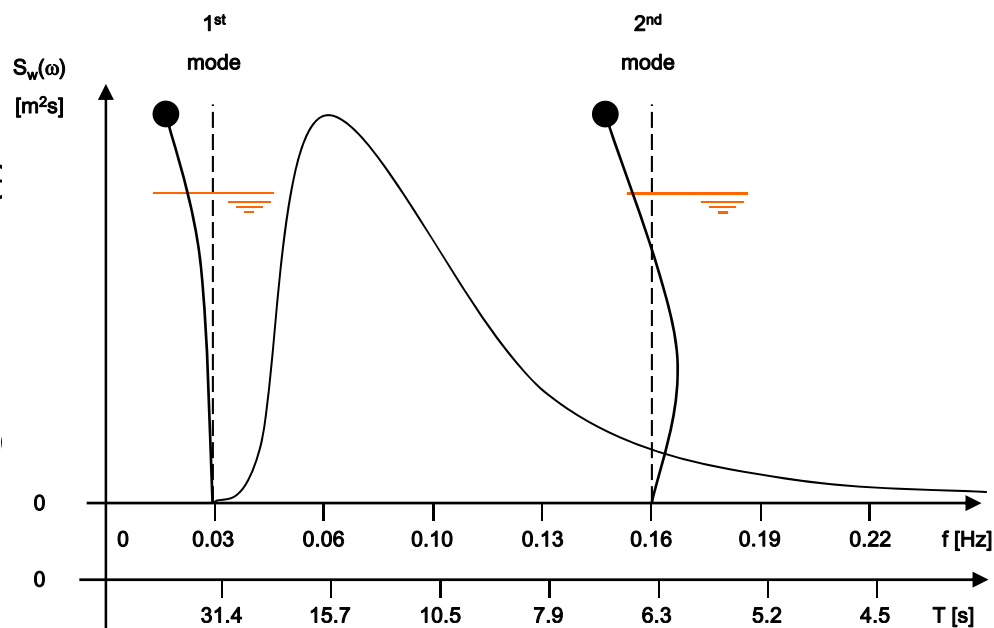
# UPWIND: Foundations and support structures



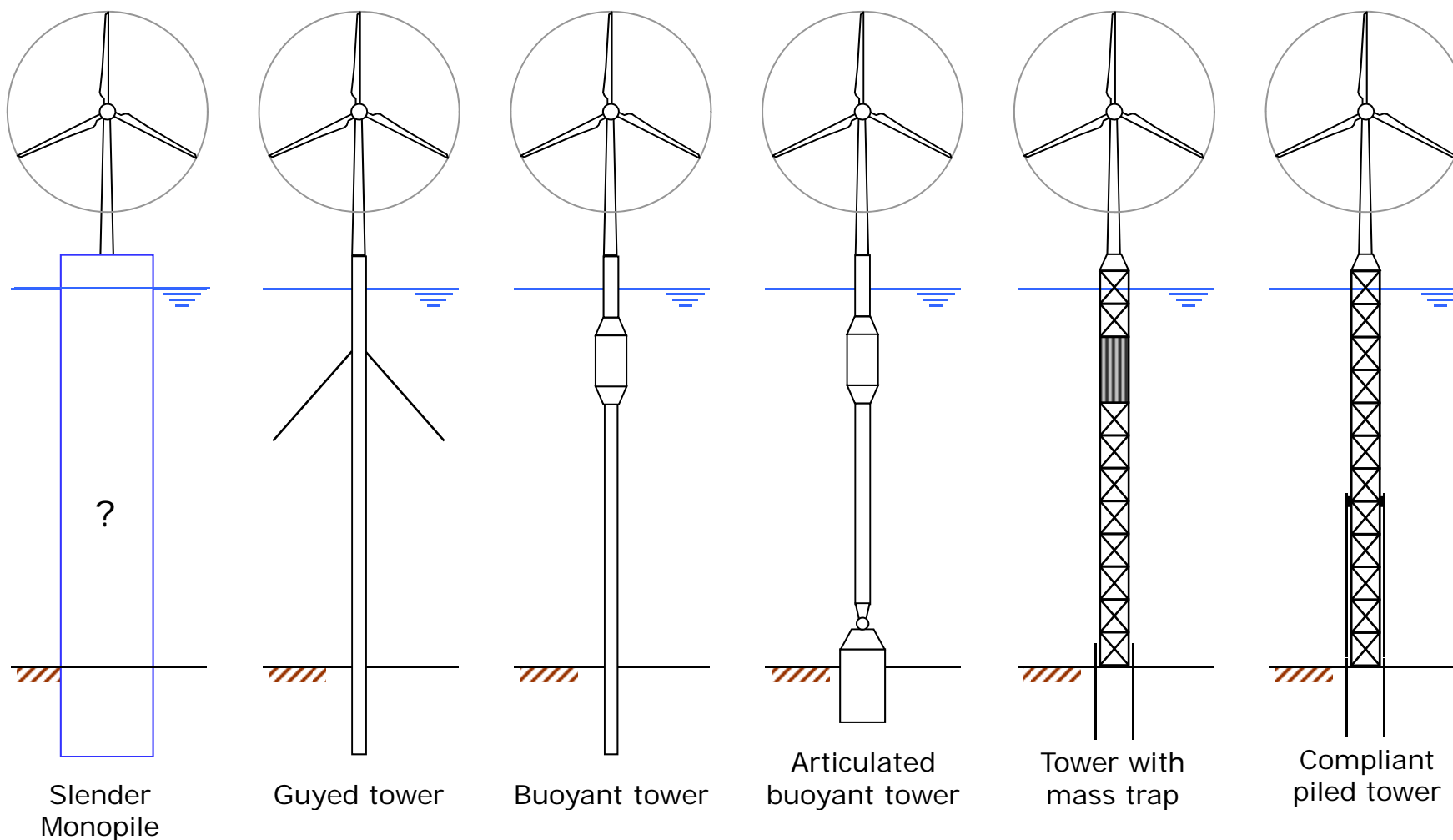
# Compliant structures: How do they work?

Design structure such that:

- 1<sup>st</sup> mode 'below' wave spectrum
- 2<sup>nd</sup> mode 'above' wave spectrum

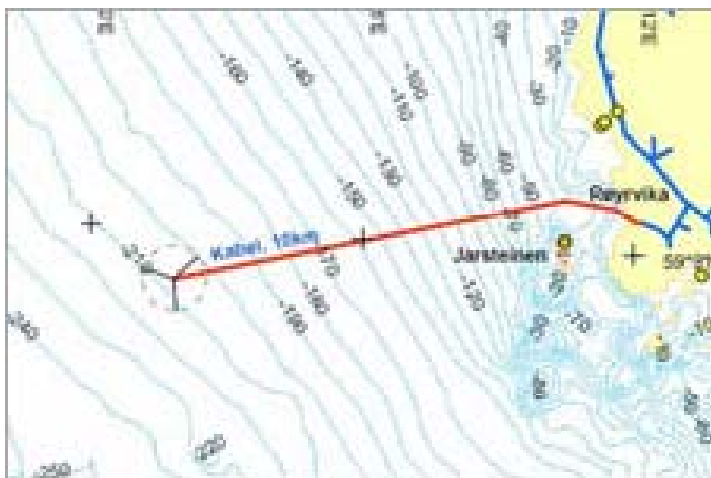


# Concepts for compliant support structures for offshore wind turbines



# HYWIND concept by StatoilHydro

- 2-5MW pitch controlled wind turbine
- Floating spar bouy attached to three mooring lines
- Intended for water depths between 120 – 700m.
- Demonstration project with Siemens 2.3MW 10km outside west coast of Norway.





# HYWIND concept - installation



- HAWC2 was used for the design loads.
- Coupled version of HAWC2 and SIMO/RIFLEX
- Stand-alone edition of HAWC2



## Focus on the HYWIND concept: Vibration modes.

New vibrations mode occurs for the floating concept

1. Horizontal translation (2 modes) 0.01Hz
2. Rigid body rotation, tilt (2modes) 0.035Hz
3. Vertical translation 0.037Hz

These modes are more low frequent than the dominating wave excitation.

For a similar on-shore turbine, the lowest Natural frequency is  
1<sup>st</sup> tower bending 0.4Hz



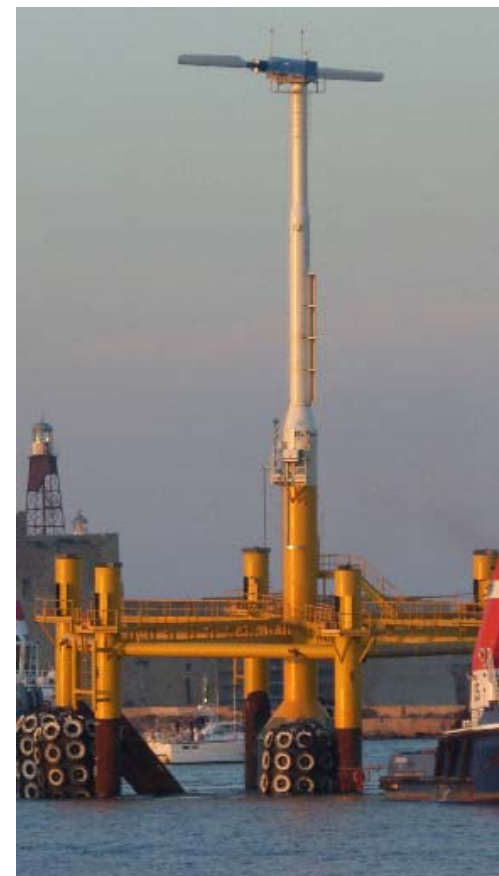
## SWAY concept

- Downwind rotor
- Wire construction to limit tower load
- Single tension leg (Stiff in torsion)
- Special joint bearing to avoid bending in tension leg
- Yaw bearing between tower bottom and tension leg
- Tower shape with non-circular shape
- Gravity anchor system

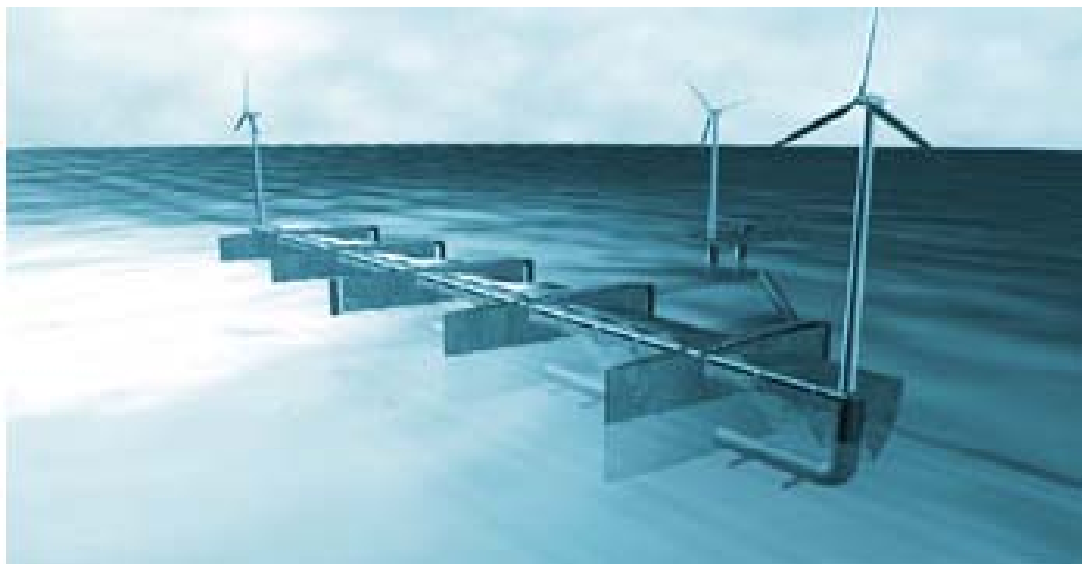


## Blue H – the first floating turbine

- Demonstration project 10km from coast of Italy ongoing
- Very sparse information available, but turbine is small and construction huge . . .



# Poseidon – Combined wave and wind



- Wave energy platform
- Dimensions are very large. Three turbines can produce extra power from wind – and contribute to the total damping of motion.





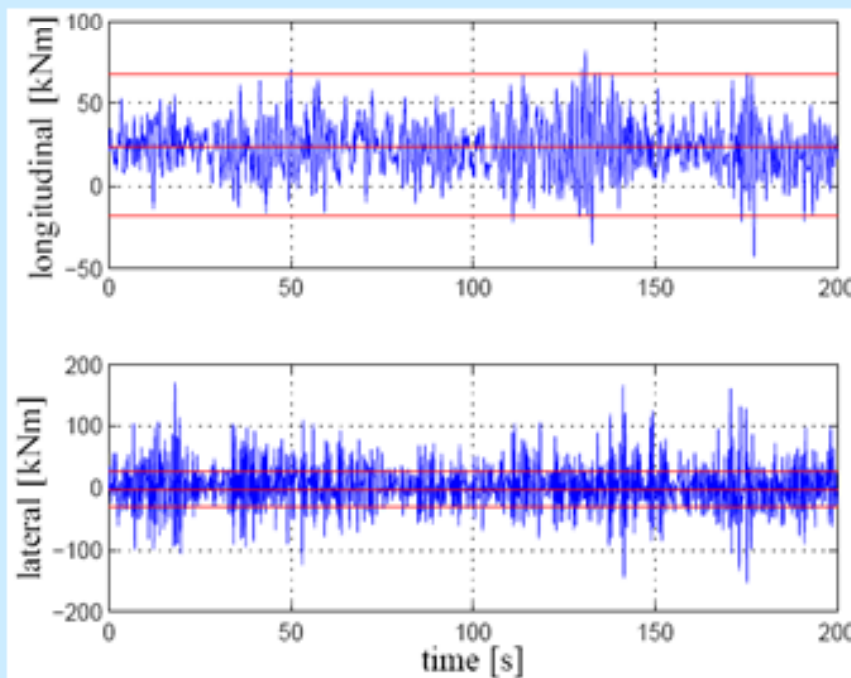
# Poseidon



**Illustration** of the three 11 kW GAIA turbines mounted on the demonstration platform. The turbines are two-bladed fixed speed down-wind turbines with free yaw and a teeter mechanism.

## Simulated Turbine Response to Measured Platform Motion

- The red lines denote min., mean and max. for simulation without the platform motion.
- Especially the lateral tower load increases, and becomes the dominating tower load.



Ongoing work:

- HAWC2 is coupled to WAMSIM (Code for floating vessel motion, DHI)
- Full aero/hydro/structure simulation for floating platform with three turbines are simulated.

## Conclusions

- Unlimited resource for offshore wind energy
- Rapid growth in installations
- EU promotion of offshore development
- Engineering challenges
- Grid integration of offshore wind a challenge and an opportunity for the power system
- Offshore development the key driver for wind power technology development
- Deep water concepts under way
  
- Offshore wind is just at the beginning – all options are open

**Thank you for your attention**